QUALITY MONITORING DURING THE INSTALLATION OF LARGE TEMPERED GLASS STRUCTURES

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Abstract. The need to ensure the quality of installation of large-sized structures made of tempered glass following European standards is emphasized, the relevance of which is emphasized with the acquisition of the status of a candidate for the EU by our country. This provides access to the construction industry to European manufacturers and exports the products of Ukrainian enterprises abroad. Unification of requirements for both fitting tools and quality control tools during the deployment and operation of large-sized tempered glass products has been ensured. The need to automate measuring operations from the moment of manufacturing tempered glass to the moment of its putting in place at the construction site is substantiated. It is shown that for the automation of measuring operations during the insertion of large-sized panes of tempered glass, it is appropriate to use optical measurement methods.

Key words: quality monitoring; large-scale constructions; standards; harmonization; tempered glass.

1. Introduction

The development trend in the construction industry is the use of sheet glass. The volume of its output is growing annually; for example, in 2022, in monetary terms, it amounted to more than 282 billion dollars US with the prospect of growth to 400 billion dollars US in 2030 [1]. Installation technologies of large sheet glass structures are quite complex and require constant monitoring and documentation of process parameters [2–7]. Buildings cannot do without glass elements, both in the form of external partitions and glass-metal facades (Fig. 1).

Until recently, rack and transom, planar, combined, frame, and frameless systems were exploited for the installation of glass facades. Today, spider technology, which is based on the embrace of a supporting frame installed around the perimeter of the glass panel, is increasingly used for finishing facades with glass material [2]. The spider method consents to implement various architectural ideas thanks to the joining of glass panels at almost any angle. In addition, this technology makes both cold and warm glazing more affordable [2, 3] (Fig. 2).

In general, some stages can be distinguished during the monitoring and documentation of the parameters of the installation processes of large-sized structures made of sheet glass [3, 4]. These are the monitoring of glass parameters, monitoring of the quality of fastening and fastening systems, checking the tightness and sealing of joints, monitoring and ensuring the equality and alignment of elements, documenting the results of quality monitoring, and proofing all quality certificates and tests. Before installation, the parameters of the tempered glass must be controlled, including thickness, uniformity, and the presence of defects such as scratches, dents, or other damage. Monitoring of the quality of tempered glass is usually carried out at the manufacturing company and includes several assays regarding the presence of defects and strength since products made of it are not subject to mechanical processing [5]. In areas of increased risk (natural, man-made, political), the impact of possible earthquakes, tsunamis, military actions, etc. should be evaluated with the possibility of numerical appraisal of vibration monitoring systems for the design of many hazards and mitigating the impact of the destruction of glass curtain walls [6]. Quality monitoring should cover all fasteners and fastening systems, including bolts, nuts, anchor plates, and screws, for compliance with strength and wear resistance requirements. Controlling the tightness and sealing of the joints of glass panels and the supporting structure is critically important to prevent moisture penetration and excessive heat loss [7]. Measurement and monitoring of geometric dimensions and deviations from the shape of large and high-precision main components are key factors in quality assurance, which sometimes leads to the need to evaluate their temperature deformations [8].

Damping fasteners and elements are implemented in construction to significantly reduce the requirements for such deformations [5, 7]. During the installation of structures made of curved glass with medium and large radii of curvature, their 3D laser inspection is worked [9]. Such laser scanners are expensive; it is advisable to exploit them during the implementation of exclusive projects. In addition, measuring equipment is needed, which ensures the accuracy of checking and analyzing the elements that affect the compressive or tensile stress of glass. Analysis during quality monitoring of the installation of large-sized structures made of tempered glass are critically important stage for ensuring quality and safety. Before starting the installation, technical documentation is analyzed, including drawings, specifications, and installation plans. It helps to understand project requirements and specifications, as well as determine the sequence of work and key monitoring points [7]. During installation, analysis of production processes and performance of work is carried out to ensure compliance with requirements and specifications. This may include monitoring dimensions, alignment, correctness of mounting, and other parameters using electro-optical systems such as optical rangefinders and laser levels. Such equipment is not sufficiently accurate in application due to the specifics of building structures. Nowadays, industrial scanners are being embraced that let obtain volumetric data of shapes, for example, Leica RTC360 (https://leica-geosystems.com/ru/products/laser-scanners/scanners/leica-rtc360), or Leica BLK360 (https:// leica-geosystems.com/ru/products/laser-scanners/scanners/blk360). However, due to the high cost and specific format of the original digital data, their using is limited.

Fig. 1. Implementation of modern architectural concepts

Fig. 2. Installation of glass blocks and elements for the realization of modern buildings

2. Drawbacks

The disadvantages of existing methods and means of measuring parameters during the installation of large glass structures are their insufficient accuracy, inconvenience of work, and high cost.

3. Goal

The goal of the current article is the research the possibilities of improvement and implementation of methods and means for measuring the linear dimensions of planes.

4. Improvement of methods and tools for measuring linear dimensions during the installation of large-sized structures made of tempered glass

According to the current Regulations for monitoring the quality of work on the arrangement of windows and doors for their sizes from 501 to 4000 mm, the maximum deviations of the dimensions of the frames of boxes and sashes or canvases of window and door blocks in assembled form should not exceed values from ±1.5 to ±4.0 mm. To ensure these requirements, mechanical or optoelectronic means can be implemented – electronic optical rangefinders and laser levels, which are not sufficiently accurate and also have significant methodical errors. First of all, it is related to the roughness of the surfaces from which the laser beam is reflected, and the correctness of its focusing. For uneven surfaces, the focus of the laser beam can be blurry, which leads to significant errors, which makes their work impossible. In addition, devices cannot ever be set up for accurate horizontal or vertical measurements. Attempts have been made to implement alternative options for the construction of optoelectronic interference gauges of thicknesses and lengths with high metrological characteristics [10–12], which have not been brought to mass production.

4.1. Proposals for the practical implementation of linear dimensions measurement

To implement the measurement of linear dimensions during the installation of large structures made of tempered glass, it is advisable to implement a combined method of using precision mechanical and optoelectronic measuring tools. To ensure the required error value of ±2.0 mm at relatively small distances, up to about 3 meters, you should choose a precision magnetic metric tape measure, for example, Milwaukee Stud 33 mm 8 m 2 accuracy class (allowable error ±0.5 mm). It is necessary to measure the dimensions, including the flatness, of a conventionally rectangular section, which is placed in one plane. To ensure measurements with the specified measurement error, in addition to a tape measure, a 30 cm ruler of accuracy class 1, for example, TOPEX 31C030 (allowable error ±0.2 mm), a laser linear level, for example, DeWALT DCE089NG18 with a limit of permissible error values of ±0.3 mm, should be exploited, as well as a laser rangefinder, for example, Bosch Professional GLM 80 (allowable error ±1.5 mm in the operating temperature range from 0° to +40 °C).

Based on a visual inspection, the places of possible deviations of the planes of the slot from equalities vertically or horizontally are determined. These can be bulges or recesses in the walls, floor, and ceiling. It is necessary to visually determine the peak points of such deviations for a more thorough inspection in these places.

It is important to determine the zero point of the horizontal plane of the floor. It is necessary to apply the distance dimension of the height on the side of the slot where the zero point is marked. The extension line of the width is always placed from the bottom, as this minimizes errors due to the deflection of the tape measure under its weight.

4.2. Determination of equalities of the vertical and horizontal planes of the slots

To reduce errors due to uneven surfaces in construction, it is suggested to implement a laser linear level with the function of self-orientation in the space of the rays, which indicates an almost ideal horizon and vertical relative to the Earth's magnetic field.

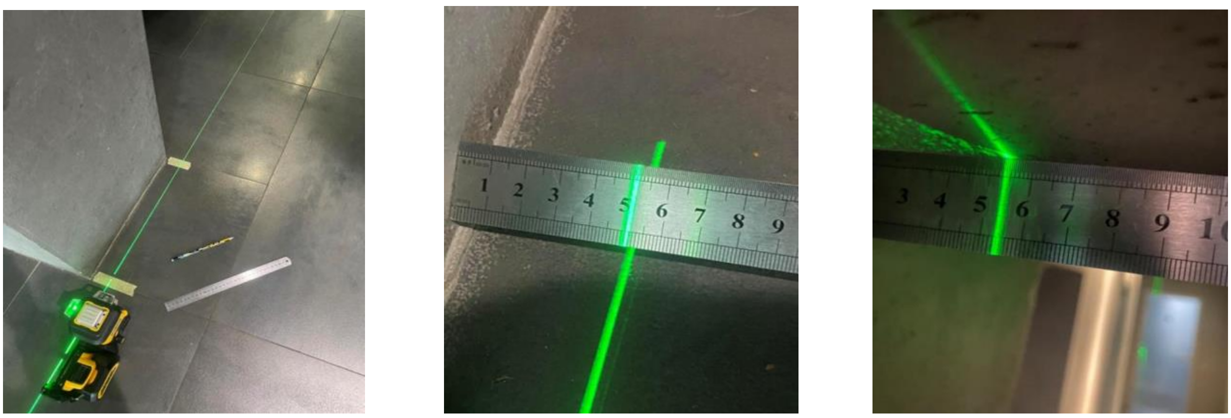
To ensure efficiency and the specified accuracy of measurements, the following measurement technique is proposed. First, the verticality of the slot planes is measured. A parallel line is drawn relative to the left part of the slot. To comfortably carry out such a measurement, it is advisable to conduct the parallel plane of the laser beam at a short distance from the slot plane – approxi- mately 5–10 cm. For each object, this distance is indi- vidual and depends on its features. To facilitate the leve- ling procedure, a tape mark is applied. After that, the same marks of the parallel plane's deviation from the laser beam are marked with a pencil, and then the beam of the laser level is set through these marks (Fig. 3, *a*).

After setting the laser level, the distance from the lower point from the cut plane to the laser beam in the place where the structure can be installed and measured by a ruler. This is approximately the middle of the slot. This size may not always coincide with the size of the displayed labels on the corners of the slot due to the unevenness of the slot itself. However, this size is assumed to be nominally zero, and the vertical deviations of the slot are calculated from it.

To obtain more accurate measurement results, you should make additional marks on the same laser level, or work another laser level and draw a vertical beam through the center of the slot so that you can see where to measure with a ruler along the contour of the exposed beam (Fig. 3, *b*). Next, measurements should be made approximately in the center and at the top point of the slot (Fig. 3, *c*). If the value of the measurement result increases uniformly, or on the contrary decreases, it means that the deviation of the plane has a direct linear relationship.

After that, the measurement results can be recorded in the measurement notebook, indicating with an arrow the deviation of the upper point, in which direction the slot plane is inclined, and at what distance from the zero value. If in the center of the visible part of the slot, a convexity or depression of the slot plane is visually noted, then it is necessary to measure the size from the slot plane to the beam of the laser level of this place.

This measurement result should be recorded in the measurement book, indicating with an arrow in which direction this deviation is and by what value. To consider these deviations, you should measure the distance from the floor or the ceiling to this place with a tape measure. These measurement results should be recorded so that when the data is subsequently entered into the CAD system, the dynamics of the deviation can be understood and corrected. If it is visually difficult to determine such places, it is suggested to continuously draw a ruler from the bottom to the very top of the slot and determine the maximum deviation based on the peak values of the results.



a *b* *c*

Fig. 3. Illustration of the measurement procedure for determining equalities along the vertical

To perform an analysis of deviations along the horizon, the laser level should be set approximately in the center of the slot height. If in the center of the visible part of the hole, a convexity or depression of the slot plane is visually noted, then it is suggested to measure the size from the slot plane to the beam of the laser level of this place and record the result in the measurement notebook, indicating with an arrow in which direction the deviation is and by what value. The distance from the floor (or from the ceiling) to the given place should be measured with a tape measure, and then the results should be recorded in a notebook so that when entering data into CAD systems, the dynamics of the deviation can be understood. If it is visually difficult to determine such places, you can continuously draw a ruler from the bottom to the very top and determine the deviation from the very peak values of the measurement.

It is suggested to start measuring with a tape measure from the floor from the place where the zero point is pre-set, for example, this is the left part of the slot. Having determined the distance from the floor to the laser beam, the nominal zero value of the horizon of the floor plane is obtained. The following measurements should be taken in the center and from the right side of the slot. The methodology for carrying out measure- ments can be the same as for determining the vertical equalities of planes. The results of the measurements are recorded in the measurement book with an indication of the value of the deviation of the right part from the floor plane, noting in which direction the deviation is and by what value. Similar measurements can be made for the ceiling plane, followed by recording the results in the measurement notebook.

After performing the above measurements, a general picture of the deviations of the slot planes, both horizontally and vertically, is obtained.

4.3. Measurement of the width and height of the slot planes and checking the results

It is suggested to embrace a tape measure and a laser level to measure the height concerning the specified requirements. You should set the laser level in the center of the slot and measure with a tape measure the value from the left part of the slot to the laser level, both from the floor and from the ceiling. The values of these results are summed up and recorded in the measurement note- book, opposite the reference height value. The analysis shows that for the right part of the slot, such measure- ments do not need to be made, since the already deter- mined value of the deviations and the value of the slot height is obtained after entering the measurement results into the CAD system.

To measure the width of the slot, you should work a tape measure with the function of adding the width of the actual body. This feature of the measuring unit allows measurements to be taken in the middle of the slot, with minimal errors for such measurements. Measurements of the width of the floor are made and the results are recorded in the measurement notebook against the reference value of the width. The analysis carried out showed that there is no need for measurements of the width at the center of the ceiling since there is already an estimate of deviations and this data can be obtained when entering into CAD systems. To check the recorded results of height and width measurements, it is necessary to operate a laser range finder. The permissible error values of such a range finder Bosch Professional GLM 80 (with a deviation of ±3.0 mm from the data recorded in the measurement notebook) can be considered accept- able. In the opposite case, it is necessary to carry out mechanical measurements with this measuring device again.

It is recommended to enter the obtained measurement results into the AutoCAD program. The project file is opened and, for convenience, a photo of the cut-out sketch from the measurement notebook is placed in the project field. After drawing the floor line from the zero point strictly vertically in the coordinate system of the program, a height line is drawn at a distance according to the entries in the measurement notebook. Deviations with width are also applied. After connecting these two points with a straight line, the vertical line of the hole plane with its dimensions and deviations is obtained. After that, a real design of the slot is received, according to which you can order the production of a large-sized structure from tempered glass.

5. Discussion and directions for further research

During measurements by the proposed method, it is the sequence of steps that is important. It eliminates errors that may occur at various stages. The possibilities of combining measurements with various equipment, both mechanical and optoelectronic, are shown. As a result, a complete picture of the geometry of this slot is obtained, as well as the dimensions for further design of the glass structure itself, with the possible correction of it following the deviations detected during measurements.

Measurement of the values of deviations of horizontal and vertical planes with a laser level is due to the physical display of the equipment itself with great accuracy. Sometimes, when re-setting, the data may differ from the previous ones by up to ±1.0 mm. Therefore, the skills of the engineer himself, who performs the binding of the equipment to the place, become important here.

To account for different thicknesses of laser levels beams and their passage through the marks must be done according to some method. Therefore, the correctness of measurements with a tape measure, its fixation, and dis- play during the measurement of vertical dimensions to the ceiling is considered important.

In more complex slot systems, the use of the spe- cified equipment may become incorrect, as in the case of exploiting a conventional rectangle. For other systems, it may be necessary to make a different sequence of ac- tions and a different set of equipment, as well as a diffe- rent method of performing measurements and recording their results with subsequent transfer to the AutoCAD system.

6. Conclusions

It is shown that the developed method of quality monitoring measurements during the installation of large structures made of tempered glass can be implemented with the necessary accuracy of the results using available and inexpensive measuring tools. When performing measurements, it is possible to reduce the error value by carrying out more detailed measurements of the geomet- ry of the object of observation, combining various methods and techniques. The perspective of processing the entered measurement results in automated design systems, for example, AutoCAD, was noted. With the increase in the volume of installation of glass surfaces, it is advisable to develop specialized systems with the possibility of saving data in one database.

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